The impact of implementing Building Information Modeling (BIM) on Occupational Health and Safety (OHS) during construction

Jonathan Matthei [1], Jimmy Abualdenien [2]

[1]KTH, School of Architecture and the Built Environment (ABE), Real Estate and Construction Management
[2]Technical University of Munich, Chair of Computational Modeling and Simulation

Abstract

The German construction industry suffers from consistently high accident figures. In recent years, there has been no discernible trend toward a decrease in occupational accidents on construction sites, resulting in over 110,000 accidents annually. In line with the BIM Roadmap published by the German Ministry of Transport in 2015, it can be recognized that Building Information Modeling (BIM) is increasingly being used. Nevertheless, safety planning often remains paper-based, manual and thus error-prone. In this regard, traditional safety planning does not seem to be able to ensure sufficient occupational health and safety during construction. This paper aims to identify how BIM could positively impact Occupational Health and Safety (OHS) during construction. Therefore, a study procedure, combining quantitative and qualitative research with an in depth literature review is introduced. This study reveals a high added value of using BIM for (1) safety rule checking and design validation and (2) safety education, training, and communication. The BIM related safety applications offer clear advantages compared to traditional safety planning approaches. Nevertheless, all of the introduced applications could be assigned a clear limitation, which restrict their potential impact on OHS. The findings further indicate that those working on the construction site have a positive attitude towards digital plans, new technologies and 3D views. There is a high potential of using BIM as a decision supporting tool to reduce the underestimation of safety hazards and to improve safety reporting. In this context, an anonymous digital application for safety reporting purposes is suggested.

Keywords: Building Information Modeling (BIM), Occupational Health and Safety (OHS), AEC industry in Germany, safety planning

1 Overview and problem statement

Work in the construction industry is one of the most dangerous professions. Therefore, historically, the construction industry is often considered to have the highest number of work-related accidents compared to other industries [1]. Construction accidents cause project delays and budget overruns, while in the worst cases they lead to the loss of human life. Within the field of construction, a lot of efforts have been made to improve occupational health and safety (OHS) during construction [2]. Legislation, safety awareness campaigns, safety training, defined rules and regulations or the development of a safety culture are just a few examples. Nevertheless, work-related injury and fatality rates in the construction sector remain on a consistently high level [3].

The German construction industry witnessed an average of 110,000 accidents per year in the period from 2010 to 2019 [4]. At the same time, an average of 77 fatalities per year was observed. This corresponds to 30.2 fatal accidents per one million full-time employees in 2019. Therefore, the construction industry in Germany represents the most dangerous work sector in terms of fatal occupational accidents in 2019. A trend, related to the absolute numbers, is not discernible.

There is common agreement in the architecture, engineering and construction (AEC) industry, that the implementation of Building Information Modeling (BIM) is changing the way projects are carried out [5]. BIM methods offer significant advantages compared to traditional paper- or two-dimensional drawing-based workflows [6]. Benefits related to a reduction of costs and risks with respect to time and budget overruns are researched [7]. In line with the BIM Roadmap published by the German Ministry of Transport in 2015, it can be recognized that BIM is supposed to get increasingly used in upcoming years. A clear desire for a digital transformation of the construction industry can be recognized. In this context, all upcoming federal infrastructure projects in Germany have to take into account a certain standard with regard to the implementation of BIM methods from the end of 2020 [8]. While BIM has been widely used for project planning and process monitoring, construction safety planning continues to rely on traditional safety sources such as paper-based regulations, two-dimensional drawings, and tacit information [9]. Vulnerable information is still predominantly handed over in the form of drawings, either as physical printed plots on paper or in digital, but limited format [10]. Such delivery methods are often the main cause of the loss of valuable information [6]. Accordingly, traditional safety planning does not seem to be able to guarantee sufficient health and safety during construction.

The purpose of this paper is to identify how BIM could positively impact OHS during construction. In this context, it is first necessary to elaborate the potential of using BIM in relation to OHS. Therefore, current applications focusing on the usage of BIM for OHS need to be investigated in detail. This part aims to clearly identify the purposes of using BIM. Subsequently, current vulnerabilities of the construction site and the potential of BIM related to OHS needs to be discussed in detail. The result of this study provides a starting point for further investigation of BIM in OHS. As part of this paper´s contribution, recommendations are provided, while challenges and requirements are discussed in more detail. The knowledge gained from this study can be used by the AEC industry to improve health and safety not only at the national level, but rather on an international and holistic scale.

2 Methodology

The study procedure started with an in-depth literature review about so called "BIM related safety applications". These are applications that specifically indicated as a BIM related application for health and safety purposes during design and construction. Based on the conducted literature review, a mixed method research approach, combining quantitative and qualitative research, was carried out. The quantitative research allowed a clear picture of current safety conditions and activities on German construction sites. Furthermore, it illustrated the acceptance of workers on the construction site towards new technologies. The quantitative research was performed through an online survey. The target group was defined as those who regularly work on construction sites or those who regularly encounter construction site activities. In total 106 people workers have participated in the survey. From the 106 participants, almost half (absolute number: 50) defined themselves as "site managers". This corresponds to a percentage of 47%. At the same time, 30 participants selected "foreman" as their current job position. This represents a percentage of 28%. In addition, nearly one quarter of the participants (24%) chose the option "none of the above". Thus, they do not assign their current job position to the one of a site manager, foreman, or construction worker. The smallest group is represented by construction workers. Only 1% of the participants selected this option as their current job position.

Subsequently, a qualitative research through semi-structured interviews was carried out. This procedure facilitated gathering input from the literature review and the quantitative study beforehand. Project manager (with BIM experience), BIM Manager and BIM Coordinator were identified as the target group of the interviews. This group was considered to be familiar with the application of BIM. Furthermore, based on their experience and knowledge of BIM, possible implementations related to the use of BIM for OHS purposes could be discussed. In total 11 interviews were conducted. All of the participants were experienced with the BIM methodology. In this context, 9 different job titles could be related to the 11 different participants. The job title "BIM Manager" was the only one mentioned several times. This title applied to 3 participants. In the following, the interview participants are assigned a letter. Therefore, participant A till participant K correspond to the 11 interview participants of the qualitative research.

3 BIM related safety applications

According to Teizer & Melzner (2018) there are only a limited amount of research activities focusing on the use of BIM related to OHS during construction [11]. However, in recent years, various technologies and methods have been developed with the aim of finding new ways to improve safety management [12]. In this context, the development of BIM applications related to occupational health and safety during design and construction has increased in the last few years [13]. Zhang et al. (2013) stated that BIM can be assigned the potential to change the way safety can be approached [5]. The applications provide new opportunities to improve safety during design and construction and hence minimize potential accidents including their far-reaching consequences. In this context, the applications often used BIM in conjunction with other technologies [14]. Martínez-Aires et al. (2018) concluded that the AEC industry would greatly benefit by using BIM as a tool that contributes to safety management [12]. Similar, Getuli et al. (2017, p.455) stated that BIM "*could be the right support in changing the way construction site safety can be approached*" [15].

3.1 BIM for safety rule checking and design validation

BIM facilitates the use of virtual safety controls to detect safety hazards [5]. Safety issues respectively design clashes can be identified, visualized and minimized during design and construction [13]. Consequently, the likelihood of accidents during construction will be reduced. Hadikusumo & Rowlinson (2004) further pointed out that three-dimensional (3D) or four-dimensional (4D) visualizations can be more effectively used for hazard recognition than conventional two-dimensional (2D) drawings [16]. In this context, BIM is assigned the potential to advance safety management by linking safety with other construction planning processes [3]. Raised awareness and improved safety planning by integrating design and construction with safety management is the claimed outcome.

The following table provides an overview of currently developed (in the period 2011-2020) applications that focus on the use of BIM for safety rule checking and design validation (see table 1). Depending on their integration with the project´s life cycle, they are assigned to a project phase, either design or design and construction. The applications related exclusively to the design phase are considered first. Moreover, the general approach, the outlined concept and a major limitation is illustrated. These are explained in more detail in the following table or in relation to the limitations in the last subsection.

Table 1: BIM applications for safety rule checking and design validation

Author (year)	Project phase	Approach	Concept	Limitation
Malekitabar et al. (2016) [17]	Design	Implementation of safety risk drivers into the BIM model	BIM model verification due to five sets of safety risk drivers	Data interoperability due to different authoring platforms and BIM tools
Getuli et al. (2017) [15]	Design	BIM-based code checking	Design validation by translating safety codes and regulations into parametric rules	Knowledge-based/semi-automated implementation
Hossain et al. (2018) [13]	Design	DfS knowledge library for BIM-integrated safety risk reviews	Elimination of risks due to an intelligent risk review system	Lack of standardization & carried out under hypothetical and simplified conditions
Zhang et al. (2013) [5]	Design & Construction	Automated rule-based checking system for BIM models	Automated detection and visualization of safety hazards combined with the provision of safety measures	Limited to fall related hazards & high manual effort in rule interpretation

Malekitbar et al. (2016) identified five sets of safety risk drivers, namely: external drivers, contractual drivers, managerial drivers, communicational drivers and internal drivers [17]. These drivers either impact the probability or the consequence of an accident. According to their study, the defined drivers were supposed to be checked by a 4D modeling software and model checkers to determine if safety risks are likely to arise in the project. In other words, the BIM model should be verified to determine if the safety requirements are met. Getuli et al. (2017) shared the view of using BIM for verification purposes [15]. They carried out a research project aiming to provide BIM-based code checking for construction health and safety. In this context, current codes and regulations were translated into parametric rules to validate the design. Virtual inspections and information-based analysis of construction phases have thus been possible. A rule-based system consists generally of two elements, namely the rules and the design model [18]. The validation of the design provides results such as "pass", "fail", or "warning" for the cases with incomplete data [19]. The elimination of potential hazards prior to the start of construction can be defined as the outcome of their application.

A similar approach is pursued by Hossain et al. (2018) who developed a Design for Safety (DfS) knowledge library for BIM-integrated safety risk reviews [13]. The generated risk register system was designed to help designers identify risks related to their design elements. Therefore, a rule based DfS knowledge library was created that contains required design features as mitigation measures. The preliminary defined rules were consequently checked against the BIM model. This enabled tagging and highlighting relevant design elements in the BIM model within the design phase. Subsequently, the designer had the possibility to adjust the design. Zhang et al. (2013) in contrast, proposed an approach referring to the project phases design and construction [5]. They developed an automated rule-based checking system for building information models. Based on their study, a tool to analyze a building model in order to detect hazards and to suggest preventive measures was designed. Therefore, existing rules, guidelines and best practices were used in conjunction with 3D design and schedule information to formulate an automated safety rule checking system. In this context, automated rule checking can be defined as a "*software that does not modify a building design, but rather assesses a design on the basis of the configuration of objects, their relations or attributes*" [19]. The BIM-related safety application by Zhang et al. (2013) facilitated the automated detection and visualization of fall-related hazards and the initiation of appropriate actions. The application could be used during the design phase and during site inspections of the construction phase. This allowed human decision makers to modify aspects based on results provided through the automated safety rule checking system.

3.2 BIM for safety education, training, and communication

Zhang et al. (2015) have identified the potential of BIM to improve safety understanding and communication [5]. This perception is shared by Marefat et al. (2019) who stated that BIM enables better communication leading to more effective safety planning [20]. In this context, BIM is understood as the kernel of information management shared by all stakeholders involved in the lifecycle of a construction project [13]. As a result, BIM is claimed for better informed decisions by improving communication between stakeholders and the quality of available information [21]. Furthermore, the use of BIM models for safety education and training is supposed to offer on-site labor a better understanding of project conditions [20]. According to Zhang & Hu (2011) virtual tools used in this process contribute to raised awareness and sensitivity related to safety aspects [22]. The potential to understand safety hazards in this way is stated to be easier than with conventional methods [16].

The following table provides an overview of currently developed (in the period 2011-2020) applications that focus on the use of BIM for safety education, training, and communication (see table 2). Depending on their integration with the project´s life cycle, they are assigned to a project phase, either design and construction or construction. The applications related to design and construction are considered first. Furthermore, the general approach, the outlined concept and a major limitation is illustrated. These are explained in more detail in the following table or in relation to the limitations in the last subsection.

Table 2: BIM applications for safety education, training, and communication

Author (year)	Project phase	Approach	Concept	Limitation
Kiviniemi et al. (2011) [23]	Design & Construction	BIM-based 4D construction planning	Procedures and use of BIM technology for safety planning, management and communications	Lack of ready-modelled standardized site planning components
Getuli et al. (2020) [24]	Design & Construction	Methodology for site activity workspace planning by using VR in conjunction with BIM	Enhanced workspace planning process by simulating a real scale virtual construction activity	Knowledgeable workforce is required
Riaz et al. (2014) [25]	Construction	Sensor based working environment by using BIM in conjunction with wireless sensor technology	Real time monitoring of construction sites and hazard preventions	Heavy infrastructure & error-prone

The Technical Research Centre of Finland (VTT) conducted a BIM Safety research project between 2009 and 2011 [23]. In this regard the term BIM-based 4D construction planning was introduced. The term refers to the combined usage of construction schedule and a 3D computer-aided design (CAD) model. Within the scope of the study, VTT developed procedures to use BIM technology for safety planning, management and communication purposes. A BIM-based site layout plan, information display screens and virtual reality rooms were introduced in several test cases. The information display screens and virtual reality rooms were used to provide a solid understanding of the construction site. Therefore, scheduling information was linked with general site safety instructions and site-specific plans and models. The BIM-based site layout plan consisted of visualizations related to permanent building structures and temporary site facilities and equipment. The dynamic site layout planning allowed the evaluation of risks related to any possible crane collapse at the site.

Getuli et al. (2020) introduced a methodology for the simultaneous use of BIM and virtual reality (VR) for construction workplace planning [24]. The methodology consists of five steps, namely: (1) activity workspace modelling, (2) VR activity simulation, (3) data collection and analysis, (4) workspace modification and (5) onsite validation of the proposed workspaces. In this context, building components of the BIM model were used to create a virtual representation of a construction activity. Construction workers could then use the VR simulation for safety training purposes in a risk-free virtual environment. Afterwards workspace modifications in the BIM modelling environment were feasible. Furthermore, a post-planning validation was supposed to assess the consistency between the worker´s perception and the VR simulation. In contrast to these two approaches, the application developed by Riaz et al. (2014) focused exclusively on the construction phase [25]. Riaz et al. (2014) created a prototype system that explored the integration of BIM software with wireless sensor technology to create a self-updating BIM model. In this context, sensors collected and monitored data regarding oxygen and temperature levels on construction sites. Due to the connection with the BIM model, the collected data could be visualized and communicated for the use of worker safety.

3.3 Limitations of BIM related safety applications

Although the applications presented show a high potential, there are currently clear limitations associated with them. Hossain et al. (2018) mentioned that some of these applications can only prevent a particular type of hazard [13]. This can especially be associated with the application developed by Zhang et al. (2013). The application can currently only be applied to fall-related installations. Mordue & Finch (2014) further mentioned that these studies were often carried out under hypothetical and simplified conditions [26]. They are accused to reflect only a small part of what occurs in the dynamic and complex reality. As an example, the application of Hossain et al. (2018) is so far only being tested in a virtual case study. An additional limitation is mentioned by Zhang et al. (2013) who stated that rule translation into machine readable code including the selection of corresponding measures remains often to be a manual task [5]. In the applications developed by Getuli et al. (2017), all rules must first be translated manually into parametric rules. Knowledge based and semi-automated implementations are the consequence. Hard-coded algorithms can further not make complex design decisions that may require human creativity or knowledge in some circumstances [14]. In this context, it is feared that digital technologies prevent active challenging of assumptions by providing "mindless" decision making. In addition, data interoperability due to different authoring platforms and BIM tools remains a major challenge [6]. The loss-free exchange of data between applications by different vendors is considered crucial [27]. This is especially the case since model and information exchange between various project stakeholders and during several project phases is unavoidable [5]. The described risk exists, for example, when information about risk drivers needs to be communicated between different BIM and model checking platforms, as in the application of Malekitabar et al. (2016).

A further limitation is identified by Teizer & Melzner (2018) who stated that today's BIM models lack on standardization [11]. As a result, some safety applications such as site layout planning are possible in some BIM software, while they are not possible in others [3]. Additionally, temporary structures can currently not be simulated in commercial BIM platforms without extensive manual input. This is a problem in particular for applications such as the BIM-based 4D construction planning by Kiviniemi et al. (2011), which relies on a realistic site planning component. In order to ensure a successful usage of these critical elements, labor-intensive and manual activities are required. This is especially the case for the applications by Zhang et al. (2013). Furthermore, the safety application itself can lack standardization. As an example, the risk assessment system developed by Hossain et al. (2018) includes only those risks that are predefined in the knowledge library. Teizer & Melzner (2018) further claimed that the task to keep the model up to date during the construction phase can be considered complicated [11]. Dynamic or improvised changes make it often difficult to represent a current state of the construction site. As a result, a real-time representation of all uncertain conditions in a BIM model may not be possible [5]. Finally, a knowledgeable workforce has to be educated and trained before a widespread adoption by all stakeholders becomes feasible. According to the study of Teizer & Melzner (2018), the current workforce is not skilled enough to carry out these transformative processes [11]. The inevitable additional training and installation effort also leads to expenses, which in some cases can mute the benefits. Sensor technology, for example, often requires heavy, expensive infrastructure for monitoring [28]. This limitation can be related to the VR application by Getuli et al. (2020) and the supposed wireless sensor technology by Riaz et al. (2014).

4 Results and Discussion

The following table provides an overview of the findings related to the quantitative research. Therefore, the table represents the percentage for each answer option that got chosen. These findings were subsequently discussed during the qualitative research. Thus, an in detail discussion of the results is provided in the following subsections.

Table 3: Findings of the qualitative research

Question number	Statement	Strongly disagree	Disagree	Partly agree/ disagree	Agree	Strongly agree	n.a.
Q1	I feel safe during my work on the construction site	0.00%	0.00%	11.32%	47.17%	40.57%	0.94%
Q2	Potential hazards are always reported immediately	0.00%	11.32%	30.19%	36.79%	21.70%	0.00%
Q3	I believe that digital plans and 3D views can improve my safety understanding	0.00%	15.09%	31.13%	31.13%	18.87%	3.77%
Q4	I believe that new technologies can improve safety	0.00%	3.77%	17.92%	58.49%	19.81%	0.00%
Q5	I would prefer a single digital application to retrieve all safety information	0.00%	2.83%	33.02%	41.51%	19.81%	2.83%
Q6	My company is striving to improve safety	0.00%	0.00%	1.89%	32.08%	64.15%	1.89%

4.1 Current vulnerabilities on construction sites

According to the quantitative study approximately 88% of those working on the construction site feel safe during their work (see Q1). Approximately 47% agreed with the statement, while around 41% of the participants strongly agreed. This led to the question of whether hazards are underestimated, as consistently high accident rates prevail in recent years. The subsequent qualitative research identified that the underestimation of safety hazards represents a central problem the construction industry is facing. Nearly all participants of the qualitative research stated that safety hazards are getting underestimated. Only one out of eleven interview participants stated that safety hazards are not getting underestimated. However, this participant also stated that his/her experiences on site are based on individual site inspections. In contrast to this participant, other participants could demonstrate significantly longer work experience on the construction site. The topic of hazard underestimation received the attention of different research before. Pandit et al. (2019) stated that the underestimation of safety risk is a widespread problem in the construction industry [29]. Carter and Smith (2006) identified in their study that up to one third of safety hazards in the construction workplace remain undetected [30]. These studies underline the finding of this research indicating that the underestimation of safety hazards continues to be a problem currently confronted by the construction industry.

The quantitative research further revealed that safety reporting is a topic where further improvement is required (see Q2). Only approximately 58% of those working on the construction site stated that potential hazards are always reported immediately. Almost a third stated that this is only partly the case, while approximately 11% disagreed with the statement that potential hazards are always reported immediately. The subsequent qualitative research identified (1) time and cost pressure, (2) fear of the consequences and (3) improvisation and wrong assessment as the main drivers not to report a hazard immediately.

Five participants of the qualitative study defined time and cost pressure as the central reason not to report a potential hazard immediately. As an example, participant K said that "*there is an enormous time pressure on construction sites. Therefore it can be stated that time and costs are the biggest drivers on construction sites*". This contradicts to the opinion of two other participants, who attributed a rather subordinate role to time and cost pressure. Firstly, it should be noted that both the reporting of a hazard and the elimination of a hazard is associated with time expenditure. This can in certain situations lead to safety reporting being neglected. According to Nepal et al. (2006, p.182), "*working under schedule pressure and in a stressful environment has become a routine phenomenon at many construction sites*" [31]. In order to avoid delays and additional costs, schedule pressure is therefore exercised on site personnel. The emerging time and cost pressure suggests that hazards are not always reported immediately. This is defined by the majority of the interview participants as a main driver not to report a hazard immediately. However, since two interview participants assigned time and cost pressure a less important role, the mechanism to report safety hazards seems to be influenced by other drivers as well. Three participants assigned the fear of the consequences a central role for immediate hazard reporting. In this context, participant A stated that "*the fear to get criticized for doing something wrong represents a central reason not to report a hazard immediately*". This is in line with study carried out by van der Schaaf & Kanse (2004) who defined the fear of a disciplinary action due to a so called "blame culture" a central factor influencing the reporting of safety hazards [32]. Furthermore, seven participants claimed that site personnel tends to improvise or wrongly assess hazardous situations. As an example, participant D stated that "*improvisation and the fact that hazards are often not perceived as a dangerous irritation are main reasons not to report a hazard. This is in line with insufficient hazard awareness*". Participant K said in this context, that "*you try to sort it out yourself before you discuss it in a wider circle*". To a certain extent, this can be explained by the fact that the construction industry is considered more dangerous than other industries [1]. Therefore, hazards are already perceived as commonplace.

In summary, the underestimation of safety hazards and safety reporting are identified as current vulnerabilities the construction industry is facing. Safety reporting is in this context directly impacted by the drivers (1) time and cost pressure, (2) fear of the consequences and (3) improvisation and wrong assessment.

4.2 The potential of BIM for OHS

The findings of the mixed method research approach indicate a high potential of using BIM for the assigned purposes of (1) safety rule checking and design validation and (2) safety education, training, and communication. All participants of the qualitative study could imagine using BIM for safety rule checking and design validation. As an example, participant E stated that "*a BIM related safety application, like the one by Zhang et al. (2013), would make absolute sense and be of a great advantage*". A similar result was found regarding the potential of BIM for safety education, training, and communication. Nearly all participants of the qualitative research could imagine using BIM for these purposes. As an example, participant J said, "*I can definitely imagine it creating an added value*". In this context the added value of using BIM in conjunction with VR was mentioned several times. Only participant I was more skeptical, saying that "*it is difficult to make it realistic enough. Therefore it is more like putting gimmicks on the agenda*". This view is in line with the introduced limitation during the literature review, saying that studies using BIM for health and safety are often carried out under simplified conditions. Therefore, they represent only a part of reality. Participant I nevertheless believes that BIM could have a positive impact on safety education as it raises awareness.

In this context, digital plans, 3D views and new technologies can be considered to have a high potential for building safety understanding. The quantitative study identified that 50% of those working on the construction site can imagine that digital plans and 3D views will improve their safety understanding (see Q3). At the same time, approximately 30% can partly imagine it. The belief in a positive impact of new technologies is approximately 78%, while an additional 18% can partly imagine it (see Q4). Nevertheless, this study also identified skepticism with regards to the impact of digital plans and 3D view on safety understanding. While 50% of those working on the construction site could imagine digital plans and 3D views having a positive impact on their safety understanding, there are also approximately 15% who do not. Participants A, C and E of the qualitative study explained this result due to the fact that site personnel might not be familiar with digital plans and 3D views. As an example, participant C stated that "*some of the respondents will probably not even be familiar with this new topic*". This is consistent with the allegation that the construction industry is often seen as conservative and resistant to change [6]. Therefore, a construction worker or a site manager might not be in touch with this kind of technology. Nevertheless, if those who at least partly believe in a positive impact of digital plans and 3D views are considered as well, then the total number of those working on the construction site who believe in these tools is approximately 81%. This represents the clear majority. Therefore, it can be said that despite skepticism, the majority believe that digital plans and 3D views could have a positive impact on safety understanding.

The qualitative research further revealed clear advantages of digital plans, 3D view and new technologies, which can be summarized in a better basis for decision-making. Visual understanding and communication is identified as a clear advantage. Participant B stated that "*the visual understanding of digital plans and 3D views is higher than with paper drawings*". Furthermore, the identification and the discussion of the hazards is mentioned as a way these applications can improve safety. As an example, participant F said that "*technology can help us to be more aware of hazards and thus be safer*". Raised awareness related to safety aspects is the outcome. This is in line with Zhang & Hu (2011), who stated that virtual tools can contribute positively to awareness and sensitivity [22]. Awareness and sensitivity are in particular important since the underestimation of safety hazards is identified as a central issue the construction industry is facing.

Furthermore, this study outlined the potential of a digital application as a reporting system for safety hazards (see Q5). Safety reporting is identified as an activity to which potential for improvement can be attributed. This study identified a great desire from those working on the construction site for a single digital application to retrieve all safety information. Approximately 61% would prefer a single digital application, while around 33% would at least be partly in favor of it. Therefore, it can be concluded that a digital application for the reporting of safety hazards seems beneficial. In this context, participant G said, "*the feature to report hazards would be beneficial*". This view is shared by participant A, who said that "*how to report and communicate accidents*" is a feature a digital application should provide. A digital application, as a safety reporting tool, offers the opportunity to reduce improvisation and wrong assessment as main drivers not to report a hazard. The digital application could provide clear instructions, information, and visualizations that would only be possible to a limited extent with traditional methods. In this context, BIM can be defined as a decision supporting tool, rather than as a decision-making tool. Furthermore, an anonymous reporting function seems beneficial. This idea is based on Hinze et al. (2013) who suggested that the workers may decide if they will disclose their identity, when reporting hazardous situations [33]. The reduction of the fear of consequences, which is another identified main driver for not reporting a safety risk immediately, would be the consequence. In this context, the potential of using new approaches like BIM to improve OHS is reinforced by the fact that safety is an aspect companies are striving to improve. Approximately 96% of the participants agreed or strongly agreed with the statement "My company is striving to improve safety" (see Q6).

5 Conclusion

Health and safety during construction remains a worldwide challenge the construction industry is facing. Construction accidents cause project delays and budget overruns, while in the worst cases they lead to the loss of human life. Traditional safety planning does not seem to be able to guarantee sufficient health and safety during construction. In this context, it is essential to identify new ways to improve occupational health and safety (OHS). The aim of this paper was to identify how Building Information Modeling (BIM) could positively impact OHS during construction. Therefore, a study procedure, following a mixed method research approach got introduced. This approach combined quantitative and qualitative research, based on an in-depth literature review about so-called "BIM related safety application".

The literature review revealed the potential impact of implementing BIM on OHS. Therefore, current applications (conducted between 2011 and 2020) focusing on the usage of BIM for OHS concerns were considered more closely. In this context, BIM could be assigned to the purpose of (1) safety rule checking and design validation and (2) safety education, training, and communication. The applications related to safety rule checking and design validation provide the opportunity to detect and eliminate safety hazards, which would be very difficult to achieve with traditional safety planning methods. The applications related to safety education, training, and communication offer the opportunity to monitor, visualize, simulate and understand hazardous situations in a more effective way. Nevertheless, all of the introduced applications could be assigned a clear limitation, which restrict their potential impact on OHS.

The findings of this study indicate a high added value of using BIM for OHS. BIM as a decision supporting tool can be used to raise awareness and therefore reduce the underestimation of safety hazards. This is in particular important, since the findings of this research indicate that the underestimation of safety hazards continues to be a problem currently confronted by the construction industry. Furthermore, this study outlined the potential of a digital application as a reporting system for safety hazards. Safety reporting is identified as a current vulnerability on German construction sites. According to the results of this study, only approximately 58 % of the workers on the construction site always report hazards immediately. In this context, (1) time and cost pressure, (2) fear of the consequences and (3) improvisation and wrong assessment are identified as the main driver not to report a hazard immediately. An anonymous digital application offers the possibility to provide clear instructions, consistent information and better visualization that would only be possible to a limited extent with traditional methods. In this way, the main drivers not to report a hazard could be reduced. The potential is reinforced by the fact that companies are striving to improve safety further. At the same time, the majority of those working on the construction site have a positive attitude towards digital plans, new technologies and 3D views.

There are certain limitations associated with this study. Originally planned on-site investigations for the survey were not possible due to the Covid 19 pandemic. This resulted in low participation of construction workers as they could not be contacted directly on site. Furthermore, a limited selection opportunity related to the job position in the survey led to a high percentage of participants that selected "none of the above". Therefore, they did not refer to any of the three titles given for the selection, namely construction manager, foreman and construction worker.

BIM will further be getting used in the AEC industry. Future research could focus more on a lifecycle perspective of using BIM for OHS. Additional studies could discuss the impact of BIM for OHS related to the operation and maintenance stage. Another field of research could be the development of further BIM related safety applications. This could be based on taking into account the limitations discussed in this study. In this context, there seems to be a particular need for an anonymous reporting system. The challenge now is to recognize the potential of BIM in relation to OHS and to actively use BIM for health and safety purposes.

References

[1] Gillen, M., Faucett, J. A., Beaumont, J. J., McLoughlin, E. (1997). *Injury Severity Associated With Nonfatal Construction Falls.* American Journal of industrial medicine 32 (1997), 647-655.

[2] Choudhry, R. M. (2014). *Behavior-based safety on construction sites: A case study.* Accident Analysis and Prevention 70 (2014), 14–23.

[3] Zhang, S., Sulankivi, K., Kiviniemi, M., Romo, I., Eastman, C. M., Teizer, J. (2015). *BIM-based fall hazard identification and prevention in construction safety planning.* Safety Science 72 (2015), 31-45.

[4] DGUV (2020). *Statistik: Arbeitsunfallgeschehen 2019.* Retrieved at: https://publikationen.dguv.de/widgets/pdf/download/article/3893 [12.01.2021].

[5] Zhang, S., Teizer, J., Lee, J., Eastman, C., Venugopal M. (2013). *Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules.* Automation in Construction 29 (2013), 183-195.

[6] Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM Handbook. A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors.* John Wiley and Sons, Inc, New Jersey.

[7] Schwabe, K., Dichtl, M., König, M., Koch, C. (2018). COBie: A Specification for the Construction Operations Building Information Exchange. In: Borrmann, A., König, M., Koch, C., Beetz, J. (2018). *Building Information Modelling. Technology Foundations and Industry Practice.* 167-180. Springer.

[8] BMVI (2015). *Stufenplan Digitales Planen und Bauen.* Retrieved at: https://www.bmvi.de/SharedDocs/DE/Publikationen/DG/stufenplan-digitales-bauen.pdf?__blob=publicationFile [09.01.2021].

[9] Choe, S. & Leite, F. (2017). *Construction safety planning: Site-specific temporal and spatial information integration.* Automation in Construction 84 (2017), 335-344.

[10] Borrmann, A., König, M., Koch, C., Beetz, J. (2018). Building Information Modeling. Why? What? How?. In: Borrmann, A., König, M., Koch, C., Beetz, J. (2018). *Building Information Modelling. Technology Foundations and Industry Practice.* 1-24. Springer.

[11] Teizer, J. & Melzner, J. (2018). BIM for Construction Safety and Health. In: Borrmann, A., König, M., Koch, C., Beetz, J. (2018). B*uilding Information Modelling. Technology Foundations and Industry* Practice. 349-365. Springer.

[12] Martínez-Aires, M. D., López-Alonso, M., Martínez-Rojas, M. (2018). B*uilding information modeling and safety management: A systematic review.* Safety Science 101 (2018), 11-18.

[13] Hossain, M. A., Abbott, E. L. S., Chua, D. K. H., Qui, N. T., Goh, Y. M. (2018). *Design-for-Safety knowledge library for BIM-integrated safety risk reviews.* Automation in Construction 94 (2018), 290-302.

[14] Zhou, W., Whyte, J., Sacks, R. (2012). *Construction safety and digital design: A review.* Automation in Construction 22 (2012), 102-111.

[15] Getuli, V., Mastrolembo Ventura, S., Capone, P., Ciribini, A. L. C. (2017). *BIM-based code checking for construction health and safety.* Procedia Engineering 196 (2017), 454-461.

[16] Hadikusumo, B. H. W. & Rowlinson, S. (2004). *Capturing Safety Knowledge Using Design-for-Safety-Process Tool.* Journal of Construction Engineering and Management (2014), 281-289.

[17] Malekitabar, H., Ardeshir, A., Sebt, M. H., Stouffs, R. (2016). *Construction safety risk drivers: A BIM approach.* Safety Science 82 (2016), 445-455.

[18] Pauwels, P., Mendes de Farias, T., Zhang, C., Roxin, A., Beetz, J., De Roo, J., Nicolle, C. (2017). *A performance benchmark over semantic rule checking approaches in construction industry.* Advanced Engineering Informatics 33 (2017), 68-88.

[19] Eastman, C., Lee, J., Jeong, Y., Lee, J. (2009). *Automatic rule-based checking of building designs.* Automation in Construction 18 (2009), 1011-1033.

[20] Marefat, A., Toosi, H., Hasankhanlo, R. M. (2019). *A BIM approach for construction safety: applications, barriers and solutions.* Engineering, Construction and Architectural Management, Vol. 26 No. 9 (2019), 1855-1877.

[21] Ganah, A. & John, G. A. (2015). *Integrating Building Information Modeling and Health and Safety for Onsite Construction.* Safety and Health at Work 6 (2015), 39-45.

[22] Zhang, J.P. & Hu, Z.Z. (2011). *BIM- and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 1. Principles and methodologies.* Automation in Construction 20 (2011), 155-166.

[23] Kiviniemi, M., Sulankivi, K., Kähkönen, K., Mäkelä, T., Merivirta, M. (2011). *BIM-based Safety Management and Communication for Building Construction.* VTT Technical Research Centre Finland. Retrieved at: https://www.vttresearch.com/sites/default/files/pdf/tiedotteet/2011/T2597.pdf [09.02.2021].

[24] Getuli, V., Capone, P., Bruttini, A., Isaac, S. (2020). *BIM-based immersive Virtual Reality for construction workspace planning: A safety-oriented approach.* Automation in Construction 114 (2020), 103-160.

[25] Riaz, Z., Arslan, M., Kiani, A. K., Azhar, S. (2014). *CoSMoS: A BIM and wireless sensor based integrated solution for worker safety in confined spaces.* Automation in Construction 45 (2014), 96-106.

[26] Mordue, S. & Finch, R. (2014). B*IM for Construction Health and Safety.* W&G Baird Ltd in Great Britain. RIBA Publishing.

[27] Borrmann, A. Beetz, J., Koch, C., Liebich, T., Muhic, S. (2018b). Industry Foundation Classes: A Standardized Data Model for the Vendor-Neutral Exchange of Digital Building Models. In: Borrmann, A., König, M., Koch, C., Beetz, J. (2018). *Building Information Modelling. Technology Foundations and Industry Practice.* 81-126. Springer.

[28] Park, J. W., Kim, K., Cho, Y. K. (2017). *Framework of Automated Construction-Safety Monitoring Using Cloud-Enabled BIM and BLE Mobile Tracking Sensors.* J. Constr. Eng. Manage., 2017, 143(2): 05016019.

[29] Pandit, B., Albert, A., Patil, Y., Al-Bayati, A. J. (2019). *Impact of safety climate on hazard recognition and safety risk perception.* Safety Science 113 (2019), 44-53.

[30] Carter, G. & Smith, S., (2006). *Safety hazard identification on construction projects.* J. Constr. Eng. Manage. 132 (2), 197-205.

[31] Nepal, M. P., Park, M., Son, B. (2006). *Effects of Schedule Pressure on Construction Performance.* J. Constr. Eng. Manage., 2006, 132(2), 182-188.

[32] van der Schaaf, T. & Kanse, L. (2004). *Biases in incident reporting databases: an empirical study in the chemical process industry.* Safety Science 42 (2004), 57–67.

[33] Hinze, J., Thurman, S., Wehle, A. (2013). *Leading indicators of construction safety performance.* Safety Science 51 (2013), 23-28.